

CONTENTS

Preface xxix

Trade Mark xxxviii

PART I: Overview 1

Chapter 1 *Introduction* 3

- 1.1 DATA COMMUNICATIONS 4
 - 1.1.1 Components 4
 - 1.1.2 Data Representation 5
 - 1.1.3 Data Flow 6
- 1.2 NETWORKS 7
 - 1.2.1 Network Criteria 7
 - 1.2.2 Physical Structures 8
- 1.3 NETWORK TYPES 13
 - 1.3.1 Local Area Network 13
 - 1.3.2 Wide Area Network 14
 - 1.3.3 Switching 15
 - 1.3.4 The Internet 17
 - 1.3.5 Accessing the Internet 18
- 1.4 INTERNET HISTORY 19
 - 1.4.1 Early History 19
 - 1.4.2 Birth of the Internet 20
 - 1.4.3 Internet Today 22
- 1.5 STANDARDS AND ADMINISTRATION 22
 - 1.5.1 Internet Standards 22
 - 1.5.2 Internet Administration 24
- 1.6 END-CHAPTER MATERIALS 25
 - 1.6.1 Recommended Reading 25
 - 1.6.2 Key Terms 25
 - 1.6.3 Summary 26
- 1.7 PRACTICE SET 27
 - 1.7.1 Quizzes 27
 - 1.7.2 Questions 27
 - 1.7.3 Problems 28
- 1.8 SIMULATION EXPERIMENTS 28
 - 1.8.1 Applets 28
 - 1.8.2 Lab Assignments 28

Chapter 2 *Network Models* 31

- 2.1 PROTOCOL LAYERING 32
 - 2.1.1 Scenarios 32
 - 2.1.2 Principles of Protocol Layering 34
 - 2.1.3 Logical Connections 35

2.2	TCP/IP PROTOCOL SUITE	35
2.2.1	Layered Architecture	35
2.2.2	Layers in the TCP/IP Protocol Suite	37
2.2.3	Description of Each Layer	38
2.2.4	Encapsulation and Decapsulation	41
2.2.5	Addressing	42
2.2.6	Multiplexing and Demultiplexing	43
2.3	THE OSI MODEL	44
2.3.1	OSI versus TCP/IP	45
2.3.2	Lack of OSI Model's Success	45
2.4	END-CHAPTER MATERIALS	46
2.4.1	Recommended Reading	46
2.4.2	Key Terms	46
2.4.3	Summary	46
2.5	PRACTICE SET	47
2.5.1	Quizzes	47
2.5.2	Questions	47
2.5.3	Problems	48
PART II: Physical Layer 51		
Chapter 3 Introduction to Physical Layer 53		
3.1	DATA AND SIGNALS	54
3.1.1	Analog and Digital Data	55
3.1.2	Analog and Digital Signals	55
3.1.3	Periodic and Nonperiodic	56
3.2	PERIODIC ANALOG SIGNALS	56
3.2.1	Sine Wave	56
3.2.2	Phase	59
3.2.3	Wavelength	61
3.2.4	Time and Frequency Domains	61
3.2.5	Composite Signals	63
3.2.6	Bandwidth	65
3.3	DIGITAL SIGNALS	68
3.3.1	Bit Rate	69
3.3.2	Bit Length	69
3.3.3	Digital Signal as a Composite Analog Signal	70
3.3.4	Transmission of Digital Signals	70
3.4	TRANSMISSION IMPAIRMENT	76
3.4.1	Attenuation	77
3.4.2	Distortion	79
3.4.3	Noise	79
3.5	DATA RATE LIMITS	81
3.5.1	Noiseless Channel: Nyquist Bit Rate	81
3.5.2	Noisy Channel: Shannon Capacity	82
3.5.3	Using Both Limits	83

3.6	PERFORMANCE	84
3.6.1	Bandwidth	84
3.6.2	Throughput	85
3.6.3	Latency (Delay)	85
3.6.4	Bandwidth-Delay Product	87
3.6.5	Jitter	88
3.7	END-CHAPTER MATERIALS	89
3.7.1	Recommended Reading	89
3.7.2	Key Terms	89
3.7.3	Summary	89
3.8	PRACTICE SET	90
3.8.1	Quizzes	90
3.8.2	Questions	90
3.8.3	Problems	91
3.9	SIMULATION EXPERIMENTS	94
3.9.1	Applets	94

Chapter 4 *Digital Transmission* 95

4.1	DIGITAL-TO-DIGITAL CONVERSION	96
4.1.1	Line Coding	96
4.1.2	Line Coding Schemes	100
4.1.3	Block Coding	109
4.1.4	Scrambling	113
4.2	ANALOG-TO-DIGITAL CONVERSION	115
4.2.1	Pulse Code Modulation (PCM)	115
4.2.2	Delta Modulation (DM)	123
4.3	TRANSMISSION MODES	125
4.3.1	Parallel Transmission	125
4.3.2	Serial Transmission	126
4.4	END-CHAPTER MATERIALS	129
4.4.1	Recommended Reading	129
4.4.2	Key Terms	130
4.4.3	Summary	130
4.5	PRACTICE SET	131
4.5.1	Quizzes	131
4.5.2	Questions	131
4.5.3	Problems	131
4.6	SIMULATION EXPERIMENTS	134
4.6.1	Applets	134

Chapter 5 *Analog Transmission* 135

5.1	DIGITAL-TO-ANALOG CONVERSION	136
5.1.1	Aspects of Digital-to-Analog Conversion	137
5.1.2	Amplitude Shift Keying	138
5.1.3	Frequency Shift Keying	140
5.1.4	Phase Shift Keying	142
5.1.5	Quadrature Amplitude Modulation	146

- 5.2 ANALOG-TO-ANALOG CONVERSION 147
 - 5.2.1 Amplitude Modulation (AM) 147
 - 5.2.2 Frequency Modulation (FM) 148
 - 5.2.3 Phase Modulation (PM) 149
- 5.3 END-CHAPTER MATERIALS 151
 - 5.3.1 Recommended Reading 151
 - 5.3.2 Key Terms 151
 - 5.3.3 Summary 151
- 5.4 PRACTICE SET 152
 - 5.4.1 Quizzes 152
 - 5.4.2 Questions 152
 - 5.4.3 Problems 153
- 5.5 SIMULATION EXPERIMENTS 154
 - 5.5.1 Applets 154

Chapter 6 *Bandwidth Utilization: Multiplexing and Spectrum Spreading* 155

- 6.1 MULTIPLEXING 156
 - 6.1.1 Frequency-Division Multiplexing 157
 - 6.1.2 Wavelength-Division Multiplexing 162
 - 6.1.3 Time-Division Multiplexing 163
- 6.2 SPREAD SPECTRUM 175
 - 6.2.1 Frequency Hopping Spread Spectrum 176
 - 6.2.2 Direct Sequence Spread Spectrum 178
- 6.3 END-CHAPTER MATERIALS 180
 - 6.3.1 Recommended Reading 180
 - 6.3.2 Key Terms 180
 - 6.3.3 Summary 180
- 6.4 PRACTICE SET 181
 - 6.4.1 Quizzes 181
 - 6.4.2 Questions 181
 - 6.4.3 Problems 182
- 6.5 SIMULATION EXPERIMENTS 184
 - 6.5.1 Applets 184

Chapter 7 *Transmission Media* 185

- 7.1 INTRODUCTION 186
- 7.2 GUIDED MEDIA 187
 - 7.2.1 Twisted-Pair Cable 187
 - 7.2.2 Coaxial Cable 190
 - 7.2.3 Fiber-Optic Cable 192
- 7.3 UNGUIDED MEDIA: WIRELESS 197
 - 7.3.1 Radio Waves 199
 - 7.3.2 Microwaves 200
 - 7.3.3 Infrared 201

7.4	END-CHAPTER MATERIALS	202
7.4.1	Recommended Reading	202
7.4.2	Key Terms	202
7.4.3	Summary	203
7.5	PRACTICE SET	203
7.5.1	Quizzes	203
7.5.2	Questions	203
7.5.3	Problems	204

Chapter 8 *Switching* 207

8.1	INTRODUCTION	208
8.1.1	Three Methods of Switching	208
8.1.2	Switching and TCP/IP Layers	209
8.2	CIRCUIT-SWITCHED NETWORKS	209
8.2.1	Three Phases	211
8.2.2	Efficiency	212
8.2.3	Delay	213
8.3	PACKET SWITCHING	213
8.3.1	Datagram Networks	214
8.3.2	Virtual-Circuit Networks	216
8.4	STRUCTURE OF A SWITCH	222
8.4.1	Structure of Circuit Switches	222
8.4.2	Structure of Packet Switches	226
8.5	END-CHAPTER MATERIALS	230
8.5.1	Recommended Reading	230
8.5.2	Key terms	230
8.5.3	Summary	230
8.6	PRACTICE SET	231
8.6.1	Quizzes	231
8.6.2	Questions	231
8.6.3	Problems	231
8.7	SIMULATION EXPERIMENTS	234
8.7.1	Applets	234

PART III: Data-Link Layer 235

Chapter 9 *Introduction to Data-Link Layer* 237

9.1	INTRODUCTION	238
9.1.1	Nodes and Links	239
9.1.2	Services	239
9.1.3	Two Categories of Links	241
9.1.4	Two Sublayers	242
9.2	LINK-LAYER ADDRESSING	242
9.2.1	Three Types of addresses	244
9.2.2	Address Resolution Protocol (ARP)	245
9.2.3	An Example of Communication	248

9.3	END-CHAPTER MATERIALS	252
9.3.1	Recommended Reading	252
9.3.2	Key Terms	252
9.3.3	Summary	252
9.4	PRACTICE SET	253
9.4.1	Quizzes	253
9.4.2	Questions	253
9.4.3	Problems	254
Chapter 10 <i>Error Detection and Correction</i> 257		
10.1	INTRODUCTION	258
10.1.1	Types of Errors	258
10.1.2	Redundancy	258
10.1.3	Detection versus Correction	258
10.1.4	Coding	259
10.2	BLOCK CODING	259
10.2.1	Error Detection	259
10.3	CYCLIC CODES	264
10.3.1	Cyclic Redundancy Check	264
10.3.2	Polynomials	267
10.3.3	Cyclic Code Encoder Using Polynomials	269
10.3.4	Cyclic Code Analysis	270
10.3.5	Advantages of Cyclic Codes	274
10.3.6	Other Cyclic Codes	274
10.3.7	Hardware Implementation	274
10.4	CHECKSUM	277
10.4.1	Concept	278
10.4.2	Other Approaches to the Checksum	281
10.5	FORWARD ERROR CORRECTION	282
10.5.1	Using Hamming Distance	283
10.5.2	Using XOR	283
10.5.3	Chunk Interleaving	283
10.5.4	Combining Hamming Distance and Interleaving	284
10.5.5	Compounding High- and Low-Resolution Packets	284
10.6	END-CHAPTER MATERIALS	285
10.6.1	Recommended Reading	285
10.6.2	Key Terms	286
10.6.3	Summary	286
10.7	PRACTICE SET	287
10.7.1	Quizzes	287
10.7.2	Questions	287
10.7.3	Problems	288
10.8	SIMULATION EXPERIMENTS	292
10.8.1	Applets	292
10.9	PROGRAMMING ASSIGNMENTS	292

Chapter 11 *Data Link Control (DLC)* 293

- 11.1 DLC SERVICES 294
 - 11.1.1 Framing 294
 - 11.1.2 Flow and Error Control 297
 - 11.1.3 Connectionless and Connection-Oriented 298
- 11.2 DATA-LINK LAYER PROTOCOLS 299
 - 11.2.1 Simple Protocol 300
 - 11.2.2 Stop-and-Wait Protocol 301
 - 11.2.3 Piggybacking 304
- 11.3 HDLC 304
 - 11.3.1 Configurations and Transfer Modes 305
 - 11.3.2 Framing 305
- 11.4 POINT-TO-POINT PROTOCOL (PPP) 309
 - 11.4.1 Services 309
 - 11.4.2 Framing 310
 - 11.4.3 Transition Phases 311
 - 11.4.4 Multiplexing 312
- 11.5 END-CHAPTER MATERIALS 319
 - 11.5.1 Recommended Reading 319
 - 11.5.2 Key Terms 319
 - 11.5.3 Summary 319
- 11.6 PRACTICE SET 320
 - 11.6.1 Quizzes 320
 - 11.6.2 Questions 320
 - 11.6.3 Problems 321
- 11.7 SIMULATION EXPERIMENTS 323
 - 11.7.1 Applets 323
- 11.8 PROGRAMMING ASSIGNMENTS 323

Chapter 12 *Media Access Control (MAC)* 325

- 12.1 RANDOM ACCESS 326
 - 12.1.1 ALOHA 326
 - 12.1.2 CSMA 331
 - 12.1.3 CSMA/CD 334
 - 12.1.4 CSMA/CA 338
- 12.2 CONTROLLED ACCESS 341
 - 12.2.1 Reservation 341
 - 12.2.2 Polling 342
 - 12.2.3 Token Passing 343
- 12.3 CHANNELIZATION 344
 - 12.3.1 FDMA 344
 - 12.3.2 TDMA 346
 - 12.3.3 CDMA 347
- 12.4 END-CHAPTER MATERIALS 352
 - 12.4.1 Recommended Reading 352
 - 12.4.2 Key Terms 353
 - 12.4.3 Summary 353

- 12.5 PRACTICE SET 354
 - 12.5.1 Quizzes 354
 - 12.5.2 Questions 354
 - 12.5.3 Problems 356
- 12.6 SIMULATION EXPERIMENTS 360
 - 12.6.1 Applets 360
- 12.7 PROGRAMMING ASSIGNMENTS 360

Chapter 13 *Wired LANs: Ethernet* 361

- 13.1 ETHERNET PROTOCOL 362
 - 13.1.1 IEEE Project 802 362
 - 13.1.2 Ethernet Evolution 363
- 13.2 STANDARD ETHERNET 364
 - 13.2.1 Characteristics 364
 - 13.2.2 Addressing 366
 - 13.2.3 Access Method 368
 - 13.2.4 Efficiency of Standard Ethernet 370
 - 13.2.5 Implementation 370
 - 13.2.6 Changes in the Standard 373
- 13.3 FAST ETHERNET (100 MBPS) 376
 - 13.3.1 Access Method 377
 - 13.3.2 Physical Layer 377
- 13.4 GIGABIT ETHERNET 379
 - 13.4.1 MAC Sublayer 380
 - 13.4.2 Physical Layer 381
- 13.5 10 GIGABIT ETHERNET 382
 - 13.5.1 Implementation 382
- 13.6 END-CHAPTER MATERIALS 383
 - 13.6.1 Recommended Reading 383
 - 13.6.2 Key Terms 383
 - 13.6.3 Summary 383
- 13.7 PRACTICE SET 384
 - 13.7.1 Quizzes 384
 - 13.7.2 Questions 384
 - 13.7.3 Problems 385
- 13.8 SIMULATION EXPERIMENTS 385
 - 13.8.1 Applets 385
 - 13.8.2 Lab Assignments 386

Chapter 14 *Other Wired Networks* 387

- 14.1 TELEPHONE NETWORKS 388
 - 14.1.1 Major Components 388
 - 14.1.2 LATAs 388
 - 14.1.3 Signaling 390
 - 14.1.4 Services Provided by Telephone Networks 393
 - 14.1.5 Dial-Up Service 394
 - 14.1.6 Digital Subscriber Line (DSL) 396

14.2	CABLE NETWORKS	397
14.2.1	Traditional Cable Networks	397
14.2.2	Hybrid Fiber-Coaxial (HFC) Network	398
14.2.3	Cable TV for Data Transfer	399
14.3	SONET	400
14.3.1	Architecture	401
14.3.2	SONET Layers	403
14.3.3	SONET Frames	404
14.3.4	STS Multiplexing	412
14.3.5	SONET Networks	415
14.3.6	Virtual Tributaries	420
14.4	ATM	421
14.4.1	Design Goals	422
14.4.2	Problems	422
14.4.3	Architecture	425
14.5	END-CHAPTER MATERIALS	429
14.5.1	Recommended Reading	429
14.5.2	Key Terms	430
14.5.3	Summary	431
14.6	PRACTICE SET	432
14.6.1	Quizzes	432
14.6.2	Questions	432
14.6.3	Problems	433

Chapter 15 *Wireless LANs* 435

15.1	INTRODUCTION	436
15.1.1	Architectural Comparison	436
15.1.2	Characteristics	438
15.1.3	Access Control	438
15.2	IEEE 802.11 PROJECT	439
15.2.1	Architecture	440
15.2.2	MAC Sublayer	441
15.2.3	Addressing Mechanism	446
15.2.4	Physical Layer	448
15.3	BLUETOOTH	451
15.3.1	Architecture	451
15.3.2	Bluetooth Layers	452
15.4	END-CHAPTER MATERIALS	458
15.4.1	Further Reading	458
15.4.2	Key Terms	458
15.4.3	Summary	458
15.5	PRACTICE SET	459
15.5.1	Quizzes	459
15.5.2	Questions	459
15.5.3	Problems	460
15.6	SIMULATION EXPERIMENTS	463
15.6.1	Applets	463
15.6.2	Lab Assignments	463

Chapter 16 *Other Wireless Networks* 465

- 16.1 WiMAX 466
 - 16.1.1 Services 466
 - 16.1.2 IEEE Project 802.16 467
 - 16.1.3 Layers in Project 802.16 467
- 16.2 CELLULAR TELEPHONY 470
 - 16.2.1 Operation 471
 - 16.2.2 First Generation (1G) 473
 - 16.2.3 Second Generation (2G) 474
 - 16.2.4 Third Generation (3G) 480
 - 16.2.5 Fourth Generation (4G) 482
- 16.3 SATELLITE NETWORKS 483
 - 16.3.1 Operation 483
 - 16.3.2 GEO Satellites 485
 - 16.3.3 MEO Satellites 485
 - 16.3.4 LEO Satellites 488
- 16.4 END-CHAPTER MATERIALS 489
 - 16.4.1 Recommended Reading 489
 - 16.4.2 Key Terms 490
 - 16.4.3 Summary 490
- 16.5 PRACTICE SET 491
 - 16.5.1 Quizzes 491
 - 16.5.2 Questions 491
 - 16.5.3 Problems 491

Chapter 17 *Connecting Devices and Virtual LANs* 493

- 17.1 CONNECTING DEVICES 494
 - 17.1.1 Hubs 494
 - 17.1.2 Link-Layer Switches 495
 - 17.1.3 Routers 501
- 17.2 VIRTUAL LANS 502
 - 17.2.1 Membership 504
 - 17.2.2 Configuration 504
 - 17.2.3 Communication between Switches 505
 - 17.2.4 Advantages 506
- 17.3 END-CHAPTER MATERIALS 506
 - 17.3.1 Recommended Reading 506
 - 17.3.2 Key Terms 506
 - 17.3.3 Summary 506
- 17.4 PRACTICE SET 507
 - 17.4.1 Quizzes 507
 - 17.4.2 Questions 507
 - 17.4.3 Problems 507

PART IV: Network Layer 509**Chapter 18 *Introduction to Network Layer 511***

- 18.1 NETWORK-LAYER SERVICES 512
 - 18.1.1 Packetizing 513
 - 18.1.2 Routing and Forwarding 513
 - 18.1.3 Other Services 514
- 18.2 PACKET SWITCHING 516
 - 18.2.1 Datagram Approach: Connectionless Service 516
 - 18.2.2 Virtual-Circuit Approach: Connection-Oriented Service 517
- 18.3 NETWORK-LAYER PERFORMANCE 522
 - 18.3.1 Delay 522
 - 18.3.2 Throughput 523
 - 18.3.3 Packet Loss 525
 - 18.3.4 Congestion Control 525
- 18.4 IPV4 ADDRESSES 528
 - 18.4.1 Address Space 529
 - 18.4.2 Classful Addressing 530
 - 18.4.3 Classless Addressing 532
 - 18.4.4 Dynamic Host Configuration Protocol (DHCP) 539
 - 18.4.5 Network Address Resolution (NAT) 543
- 18.5 FORWARDING OF IP PACKETS 546
 - 18.5.1 Forwarding Based on Destination Address 547
 - 18.5.2 Forwarding Based on Label 553
 - 18.5.3 Routers as Packet Switches 555
- 18.6 END-CHAPTER MATERIALS 556
 - 18.6.1 Recommended Reading 556
 - 18.6.2 Key Terms 556
 - 18.6.3 Summary 556
- 18.7 PRACTICE SET 557
 - 18.7.1 Quizzes 557
 - 18.7.2 Questions 557
 - 18.7.3 Problems 558
- 18.8 SIMULATION EXPERIMENTS 560
 - 18.8.1 Applets 560
- 18.9 PROGRAMMING ASSIGNMENT 560

Chapter 19 *Network-Layer Protocols 561*

- 19.1 INTERNET PROTOCOL (IP) 562
 - 19.1.1 Datagram Format 563
 - 19.1.2 Fragmentation 567
 - 19.1.3 Options 572
 - 19.1.4 Security of IPv4 Datagrams 573
- 19.2 ICMPv4 574
 - 19.2.1 MESSAGES 575
 - 19.2.2 Debugging Tools 578
 - 19.2.3 ICMP Checksum 580

- 19.3 MOBILE IP 581
 - 19.3.1 Addressing 581
 - 19.3.2 Agents 583
 - 19.3.3 Three Phases 584
 - 19.3.4 Inefficiency in Mobile IP 589
- 19.4 END-CHAPTER MATERIALS 591
 - 19.4.1 Recommended Reading 591
 - 19.4.2 Key Terms 591
 - 19.4.3 Summary 591
- 19.5 PRACTICE SET 592
 - 19.5.1 Quizzes 592
 - 19.5.2 Questions 592
 - 19.5.3 Problems 593
- 19.6 SIMULATION EXPERIMENTS 594
 - 19.6.1 Applets 594
 - 19.6.2 Lab Assignments 594

Chapter 20 *Unicast Routing* 595

- 20.1 INTRODUCTION 596
 - 20.1.1 General Idea 596
 - 20.1.2 Least-Cost Routing 596
- 20.2 ROUTING ALGORITHMS 598
 - 20.2.1 Distance-Vector Routing 598
 - 20.2.2 Link-State Routing 604
 - 20.2.3 Path-Vector Routing 606
- 20.3 UNICAST ROUTING PROTOCOLS 611
 - 20.3.1 Internet Structure 611
 - 20.3.2 Routing Information Protocol (RIP) 613
 - 20.3.3 Open Shortest Path First (OSPF) 618
 - 20.3.4 Border Gateway Protocol Version 4 (BGP4) 623
- 20.4 END-CHAPTER MATERIALS 631
 - 20.4.1 Recommended Reading 631
 - 20.4.2 Key Terms 631
 - 20.4.3 Summary 632
- 20.5 PRACTICE SET 632
 - 20.5.1 Quizzes 632
 - 20.5.2 Questions 632
 - 20.5.3 Problems 634
- 20.6 SIMULATION EXPERIMENTS 637
 - 20.6.1 Applets 637
- 20.7 PROGRAMMING ASSIGNMENT 637

Chapter 21 *Multicast Routing* 639

- 21.1 INTRODUCTION 640
 - 21.1.1 Unicasting 640
 - 21.1.2 Multicasting 640
 - 21.1.3 Broadcasting 643

21.2	MULTICASTING BASICS	643
21.2.1	Multicast Addresses	643
21.2.2	Delivery at Data-Link Layer	645
21.2.3	Collecting Information about Groups	647
21.2.4	Multicast Forwarding	648
21.2.5	Two Approaches to Multicasting	649
21.3	INTRADOMAIN MULTICAST PROTOCOLS	650
21.3.1	Multicast Distance Vector (DVMRP)	651
21.3.2	Multicast Link State (MOSPF)	653
21.3.3	Protocol Independent Multicast (PIM)	654
21.4	INTERDOMAIN MULTICAST PROTOCOLS	657
21.5	IGMP	658
21.5.1	Messages	658
21.5.2	Propagation of Membership Information	659
21.5.3	Encapsulation	660
21.6	END-CHAPTER MATERIALS	660
21.6.1	Recommended Reading	660
21.6.2	Key Terms	660
21.6.3	Summary	660
21.7	PRACTICE SET	661
21.7.1	Quizzes	661
21.7.2	Questions	661
21.7.3	Problems	662
21.8	SIMULATION EXPERIMENTS	663
21.8.1	Applets	663
Chapter 22 <i>Next Generation IP</i> 665		
22.1	IPv6 ADDRESSING	666
22.1.1	Representation	666
22.1.2	Address Space	667
22.1.3	Address Space Allocation	668
22.1.4	Autoconfiguration	672
22.1.5	Renumbering	673
22.2	THE IPv6 PROTOCOL	674
22.2.1	Packet Format	674
22.2.2	Extension Header	677
22.3	THE ICMPv6 PROTOCOL	679
22.3.1	Error-Reporting Messages	679
22.3.2	Informational Messages	680
22.3.3	Neighbor-Discovery Messages	681
22.3.4	Group Membership Messages	682
22.4	TRANSITION FROM IPv4 TO IPv6	682
22.4.1	Strategies	683
22.4.2	Use of IP Addresses	684
22.5	END-CHAPTER MATERIALS	684
22.5.1	Recommended Reading	684
22.5.2	Key Terms	685
22.5.3	Summary	685

- 22.6 PRACTICE SET 685
 - 22.6.1 Quizzes 685
 - 22.6.2 Questions 685
 - 22.6.3 Problems 686
- 22.7 SIMULATION EXPERIMENTS 688
 - 22.7.1 Applets 688

PART V: Transport Layer 689

Chapter 23 *Introduction to Transport Layer 691*

- 23.1 INTRODUCTION 692
 - 23.1.1 Transport-Layer Services 693
 - 23.1.2 Connectionless and Connection-Oriented Protocols 703
- 23.2 TRANSPORT-LAYER PROTOCOLS 707
 - 23.2.1 Simple Protocol 707
 - 23.2.2 Stop-and-Wait Protocol 708
 - 23.2.3 Go-Back-*N* Protocol (GBN) 713
 - 23.2.4 Selective-Repeat Protocol 720
 - 23.2.5 Bidirectional Protocols: Piggybacking 726
- 23.3 END-CHAPTER MATERIALS 727
 - 23.3.1 Recommended Reading 727
 - 23.3.2 Key Terms 727
 - 23.3.3 Summary 728
- 23.4 PRACTICE SET 728
 - 23.4.1 Quizzes 728
 - 23.4.2 Questions 728
 - 23.4.3 Problems 729
- 23.5 SIMULATION EXPERIMENTS 733
 - 23.5.1 Applets 733
- 23.6 PROGRAMMING ASSIGNMENT 733

Chapter 24 *Transport-Layer Protocols 735*

- 24.1 INTRODUCTION 736
 - 24.1.1 Services 736
 - 24.1.2 Port Numbers 736
- 24.2 USER DATAGRAM PROTOCOL 737
 - 24.2.1 User Datagram 737
 - 24.2.2 UDP Services 738
 - 24.2.3 UDP Applications 741
- 24.3 TRANSMISSION CONTROL PROTOCOL 743
 - 24.3.1 TCP Services 743
 - 24.3.2 TCP Features 746
 - 24.3.3 Segment 748
 - 24.3.4 A TCP Connection 750
 - 24.3.5 State Transition Diagram 756
 - 24.3.6 Windows in TCP 760
 - 24.3.7 Flow Control 762
 - 24.3.8 Error Control 768
 - 24.3.9 TCP Congestion Control 777

24.3.10	TCP Timers	786
24.3.11	Options	790
24.4	SCTP	791
24.4.1	SCTP Services	791
24.4.2	SCTP Features	792
24.4.3	Packet Format	794
24.4.4	An SCTP Association	796
24.4.5	Flow Control	799
24.4.6	Error Control	801
24.5	END-CHAPTER MATERIALS	805
24.5.1	Recommended Reading	805
24.5.2	Key Terms	805
24.5.3	Summary	805
24.6	PRACTICE SET	806
24.6.1	Quizzes	806
24.6.2	Questions	806
24.6.3	Problems	809

PART VI: Application Layer 815

Chapter 25 *Introduction to Application Layer* 817

25.1	INTRODUCTION	818
25.1.1	Providing Services	819
25.1.2	Application-Layer Paradigms	820
25.2	CLIENT-SERVER PROGRAMMING	823
25.2.1	Application Programming Interface	823
25.2.2	Using Services of the Transport Layer	827
25.2.3	Iterative Communication Using UDP	828
25.2.4	Iterative Communication Using TCP	830
25.2.5	Concurrent Communication	832
25.3	ITERATIVE PROGRAMMING IN C	833
25.3.1	General Issues	833
25.3.2	Iterative Programming Using UDP	834
25.3.3	Iterative Programming Using TCP	837
25.4	ITERATIVE PROGRAMMING IN JAVA	842
25.4.1	Addresses and Ports	843
25.4.2	Iterative Programming Using UDP	846
25.4.3	Iterative Programming Using TCP	857
25.5	END-CHAPTER MATERIALS	865
25.5.1	Recommended Reading	865
25.5.2	Key Terms	866
25.5.3	Summary	866
25.6	PRACTICE SET	866
25.6.1	Quizzes	866
25.6.2	Questions	866
25.6.3	Problems	869
25.7	SIMULATION EXPERIMENTS	869
25.7.1	Applets	869
25.8	PROGRAMMING ASSIGNMENT	870

Chapter 26 *Standard Client-Server Protocols* 871

- 26.1 WORLD WIDE WEB AND HTTP 872
 - 26.1.1 World Wide Web 872
 - 26.1.2 HyperText Transfer Protocol (HTTP) 876
- 26.2 FTP 887
 - 26.2.1 Two Connections 888
 - 26.2.2 Control Connection 888
 - 26.2.3 Data Connection 889
 - 26.2.4 Security for FTP 891
- 26.3 ELECTRONIC MAIL 891
 - 26.3.1 Architecture 892
 - 26.3.2 Web-Based Mail 903
 - 26.3.3 E-Mail Security 904
- 26.4 TELNET 904
 - 26.4.1 Local versus Remote Logging 905
- 26.5 SECURE SHELL (SSH) 907
 - 26.5.1 Components 907
 - 26.5.2 Applications 908
- 26.6 DOMAIN NAME SYSTEM (DNS) 910
 - 26.6.1 Name Space 911
 - 26.6.2 DNS in the Internet 915
 - 26.6.3 Resolution 916
 - 26.6.4 Caching 918
 - 26.6.5 Resource Records 918
 - 26.6.6 DNS Messages 919
 - 26.6.7 Registrars 920
 - 26.6.8 DDNS 920
 - 26.6.9 Security of DNS 921
- 26.7 END-CHAPTER MATERIALS 921
 - 26.7.1 Recommended Reading 921
 - 26.7.2 Key Terms 922
 - 26.7.3 Summary 922
- 26.8 PRACTICE SET 923
 - 26.8.1 Quizzes 923
 - 26.8.2 Questions 923
 - 26.8.3 Problems 924
- 26.9 SIMULATION EXPERIMENTS 927
 - 26.9.1 Applets 927
 - 26.9.2 Lab Assignments 927

Chapter 27 *Network Management* 929

- 27.1 INTRODUCTION 930
 - 27.1.1 Configuration Management 930
 - 27.1.2 Fault Management 932
 - 27.1.3 Performance Management 933
 - 27.1.4 Security Management 933
 - 27.1.5 Accounting Management 934
- 27.2 SNMP 934
 - 27.2.1 Managers and Agents 935

27.2.2	Management Components	935
27.2.3	An Overview	937
27.2.4	SMI	938
27.2.5	MIB	942
27.2.6	SNMP	944
27.3	ASN.1	951
27.3.1	Language Basics	951
27.3.2	Data Types	952
27.3.3	Encoding	955
27.4	END-CHAPTER MATERIALS	955
27.4.1	Recommended Reading	955
27.4.2	Key Terms	956
27.4.3	Summary	956
27.5	PRACTICE SET	956
27.5.1	Quizzes	956
27.5.2	Questions	956
27.5.3	Problems	958

Chapter 28 *Multimedia* 961

28.1	COMPRESSION	962
28.1.1	Lossless Compression	962
28.1.2	Lossy Compression	972
28.2	MULTIMEDIA DATA	978
28.2.1	Text	978
28.2.2	Image	978
28.2.3	Video	982
28.2.4	Audio	984
28.3	MULTIMEDIA IN THE INTERNET	986
28.3.1	Streaming Stored Audio/Video	986
28.3.2	Streaming Live Audio/Video	989
28.3.3	Real-Time Interactive Audio/Video	990
28.4	REAL-TIME INTERACTIVE PROTOCOLS	995
28.4.1	Rationale for New Protocols	996
28.4.2	RTP	999
28.4.3	RTCP	1001
28.4.4	Session Initialization Protocol (SIP)	1005
28.4.5	H.323	1012
28.5	END-CHAPTER MATERIALS	1014
28.5.1	Recommended Reading	1014
28.5.2	Key Terms	1015
28.5.3	Summary	1015
28.6	PRACTICE SET	1016
28.6.1	Quizzes	1016
28.6.2	Questions	1016
28.6.3	Problems	1018
28.7	SIMULATION EXPERIMENTS	1021
28.7.1	Applets	1021
28.7.2	Lab Assignments	1021
28.8	PROGRAMMING ASSIGNMENTS	1022

Chapter 29 *Peer-to-Peer Paradigm* 1023

- 29.1 INTRODUCTION 1024
 - 29.1.1 P2P Networks 1024
 - 29.1.2 Distributed Hash Table (DHT) 1026
- 29.2 CHORD 1029
 - 29.2.1 Identifier Space 1029
 - 29.2.2 Finger Table 1029
 - 29.2.3 Interface 1030
 - 29.2.4 Applications 1036
- 29.3 PASTRY 1036
 - 29.3.1 Identifier Space 1036
 - 29.3.2 Routing 1037
 - 29.3.3 Application 1041
- 29.4 KADEMLIA 1041
 - 29.4.1 Identifier Space 1041
 - 29.4.2 Routing Table 1041
 - 29.4.3 K-Buckets 1044
- 29.5 BITTORRENT 1045
 - 29.5.1 BitTorrent with a Tracker 1045
 - 29.5.2 Trackerless BitTorrent 1046
- 29.6 END-CHAPTER MATERIALS 1047
 - 29.6.1 Recommended Reading 1047
 - 29.6.2 Key Terms 1047
 - 29.6.3 Summary 1047
- 29.7 PRACTICE SET 1048
 - 29.7.1 Quizzes 1048
 - 29.7.2 Questions 1048
 - 29.7.3 Problems 1048

PART VII: Topics Related to All Layers 1051

Chapter 30 *Quality of Service* 1053

- 30.1 DATA-FLOW CHARACTERISTICS 1054
 - 30.1.1 Definitions 1054
 - 30.1.2 Sensitivity of Applications 1054
 - 30.1.3 Flow Classes 1055
- 30.2 FLOW CONTROL TO IMPROVE QOS 1055
 - 30.2.1 Scheduling 1056
 - 30.2.2 Traffic Shaping or Policing 1058
 - 30.2.3 Resource Reservation 1061
 - 30.2.4 Admission Control 1062
- 30.3 INTEGRATED SERVICES (INTSERV) 1062
 - 30.3.1 Flow Specification 1062
 - 30.3.2 Admission 1063
 - 30.3.3 Service Classes 1063
 - 30.3.4 Resource Reservation Protocol (RSVP) 1063
 - 30.3.5 Problems with Integrated Services 1065
- 30.4 DIFFERENTIATED SERVICES (DFFSERV) 1066
 - 30.4.1 DS Field 1066

30.4.2	Per-Hop Behavior	1067
30.4.3	Traffic Conditioners	1067
30.5	END-CHAPTER MATERIALS	1068
30.5.1	Recommended Reading	1068
30.5.2	Key Terms	1068
30.5.3	Summary	1068
30.6	PRACTICE SET	1069
30.6.1	Quizzes	1069
30.6.2	Questions	1069
30.6.3	Problems	1070
30.7	SIMULATION EXPERIMENTS	1075
30.7.1	Applets	1075
30.8	PROGRAMMING ASSIGNMENTS	1075
Chapter 31	<i>Cryptography and Network Security</i>	1077
31.1	INTRODUCTION	1078
31.1.1	Security Goals	1078
31.1.2	Attacks	1079
31.1.3	Services and Techniques	1081
31.2	CONFIDENTIALITY	1081
31.2.1	Symmetric-Key Ciphers	1081
31.2.2	Asymmetric-Key Ciphers	1092
31.3	OTHER ASPECTS OF SECURITY	1097
31.3.1	Message Integrity	1097
31.3.2	Message Authentication	1099
31.3.3	Digital Signature	1100
31.3.4	Entity Authentication	1105
31.3.5	Key Management	1108
31.4	END-CHAPTER MATERIALS	1114
31.4.1	Recommended Reading	1114
31.4.2	Key Terms	1114
31.4.3	Summary	1114
31.5	PRACTICE SET	1115
31.5.1	Quizzes	1115
31.5.2	Questions	1115
31.5.3	Problems	1117
31.6	SIMULATION EXPERIMENTS	1121
31.6.1	Applets	1121
31.7	PROGRAMMING ASSIGNMENTS	1122
Chapter 32	<i>Internet Security</i>	1123
32.1	NETWORK-LAYER SECURITY	1124
32.1.1	Two Modes	1124
32.1.2	Two Security Protocols	1126
32.1.3	Services Provided by IPSec	1129
32.1.4	Security Association	1130
32.1.5	Internet Key Exchange (IKE)	1132
32.1.6	Virtual Private Network (VPN)	1133

32.2	TRANSPORT-LAYER SECURITY	1134
32.2.1	SSL Architecture	1135
32.2.2	Four Protocols	1138
32.3	APPLICATION-LAYER SECURITY	1140
32.3.1	E-mail Security	1141
32.3.2	Pretty Good Privacy (PGP)	1142
32.3.3	S/MIME	1147
32.4	FIREWALLS	1151
32.4.1	Packet-Filter Firewall	1152
32.4.2	Proxy Firewall	1152
32.5	END-CHAPTER MATERIALS	1153
32.5.1	Recommended Reading	1153
32.5.2	Key Terms	1154
32.5.3	Summary	1154
32.6	PRACTICE SET	1154
32.6.1	Quizzes	1154
32.6.2	Questions	1155
32.6.3	Problems	1155
32.7	SIMULATION EXPERIMENTS	1156
32.7.1	Applets	1156
32.7.2	Lab Assignments	1156

**Appendices A-H available online at
<http://www.mhhe.com/forouzan>**

Appendices

- Appendix A** *Unicode*
- Appendix B** *Positional Numbering System*
- Appendix C** *HTML, CSS, XML, and XSL*
- Appendix D** *A Touch of Probability*
- Appendix E** *Mathematical Review*
- Appendix F** *8B/6T Code*
- Appendix G** *Miscellaneous Information*
- Appendix H** *Telephone History*

Glossary 1157

References 1193

Index 1199